Analysis of Near-Surface Atmospheric Measurements Obtained During CBLAST-LOW

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LONG-TERM GOALS

The long-range goal of the proposed research is to understand air-sea interaction and coupled atmospheric and oceanic boundary layer dynamics at low wind speeds where the dynamic processes are driven and/or strongly modulated by thermal forcing. The low wind regime extends from the extreme situation where wind stress is negligible and thermal forcing dominates up to wind speeds where wave breaking and Langmuir circulations are also expected to play a role in the exchange processes. Therefore, the CBLAST-LOW investigators seek to make observations over a wide range of environmental conditions with the intent of improving our understanding of upper ocean and lower atmosphere dynamics and of the physical processes that determine both the vertical and horizontal structure of the marine boundary layers.

OBJECTIVES

The goal of CBLAST-LOW is therefore to improve our understanding of the processes that couple the marine boundary layers under these conditions using observations, numerical simulations and models. The ultimate goal is to incorporate new and/or improved parameterization of these processes in coupled models to improve marine forecasts of wind, waves and currents. For example, the boundary conditions between the ocean and atmospheric models are often provided by parameterizations based on the **bulk aerodynamic method**. This method is also widely used to estimate the fluxes from time series measurements over the ocean. This briefing describes ongoing efforts to improve bulk formula using data collected during CBLAST-LOW. Topics of interests include a discussion of wind-wave-swell interaction at low winds and heat and moisture exchange in stratified conditions.

APPROACH

To achieve some of these objectives, the array component deployed a 3-D mesoscale array to simultaneously observe the horizontal and vertical structure of the oceanic surface boundary layer south of the tower as shown in Figure 1. This mooring component also conducted intensive ship-based surveys during the intensive operating period (IOP). The ship-based surveys were coordinated with the two aircraft-based efforts that investigated spatial variability of the atmospheric boundary layer and sea surface temperature field. The combined data sets will be used in conjunction with the modeling

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14. ABSTRACT
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15. SUBJECT TERMS

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studies to seek answers to unresolved questions about how the vertical as well as the horizontal structure of the coupled boundary layers evolve.

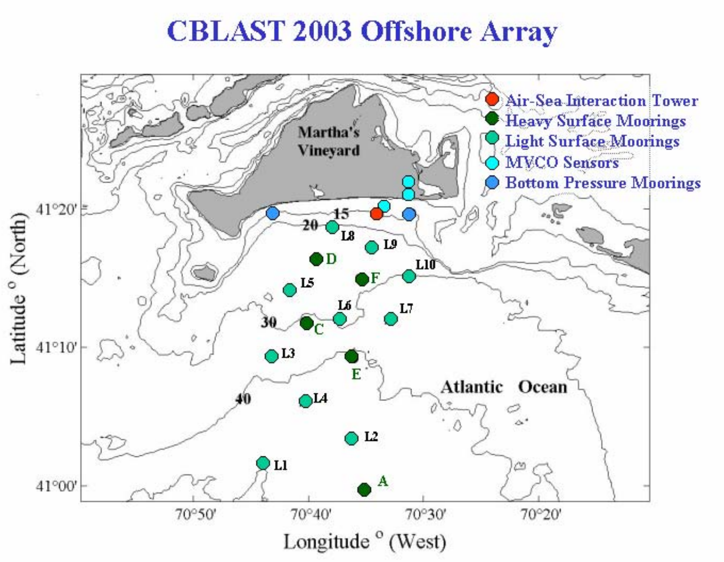

Figure 1. A diagram of the CBLAST region showing some of the assets that were deployed during the main experiment IOP in the summer 2003.

The tower component has deployed an Air-Sea Interaction Tower (ASIT) spanning the water column and the lower 22-m of the atmosphere at a water depth of 15-m at the Martha's Vineyard Coastal Observatory (MVCO) and shown in Figure 1. The 37-m tower has been instrumented with sensors to measure velocity, temperature, pressure, moisture, salinity, solar radiation, IR radiation, precipitation and waves. The tower is connected directly to shore using a fiber-optic-conductor cable, which provides Gbyte bandwidth and kWatts of power to the researchers. The velocity and temperature arrays span horizontal and vertical scales of O (1-10) m to resolve vertical structure and to permit separation and quantification of processes associated with shear- and buoyancy-generated turbulence, surface waves, and Langmuir-like coherent structures.

The IOP of the main experiment was completed in August of 2003 with some components continuing into the fall. The field work during the IOP involved substantial collaborations with John Trowbridge and Al Plueddemann, (WHOI), Wade McGillis (LDEO), and Tim Stanton (NPS) deploying complementary sensors at the ASIT; Bob Weller (WHOI) using his mooring array (see Figure 1); Larry Mahrt and Dean Vickers (OSU), Jielun Sun (NCAR), Djamal Khelif (UCI), and Haf Jonsson (CIRPAS) obtaining atmospheric measurements of turbulent fluxes, vertical profiles and horizontal variability from the LongEZ aircraft in 2001 and the CIRPAS Pelican aircraft in 2003; and Andy Jessup (UW) and Chris Zappa (LDEO) obtaining IR remote-sensing measurements. In addition, we have had substantial collaborations with regional-scale modeling groups at Rutgers University and NRL-Monterey, as well as LES investigations by Eric Skyllingstad at OSU and Peter Sullivan at NCAR. The regional-scale models are providing a context for interpreting our measurements, and our measurements will provide a means of testing estimates of turbulent fluxes and dissipation rates calculated by these models. The tower measurements of horizontal and vertical variability spanned a range of scales similar to those resolved by LES simulations and will permit a quantitative evaluation

of LES model calculations. The proposed study will produce a unique set of simultaneous measurements of turbulent fluxes and dissipation rates on both sides of the air-sea interface, as well as critical evaluations and improvements of turbulence parameterizations used in atmospheric and oceanic models. The mooring and ship survey measurements spanned a range of scales required to investigate processes on the mesoscale and, in combination with the aircraft measurements, will permit a quantitative evaluation of the coupled mesoscale model results.

WORK COMPLETED

Detailed measurements of the vertical structure of the upper ocean and lower atmosphere were successfully conducted from the ASIT during the IOP. The atmospheric arrays on ASIT were deployed in late June and recovered in early November, 2003. During this period, direct measurements of momentum, heat and mass fluxes were measured at 3-6 levels on the tower. These measurements where complemented by fixed sensors and a profiling package of sensors to compute mean profiles of velocity, temperature, and humidity. Additional measurements of the radiative fluxes, sea surface temperature, precipitation, and the wave field were collected to provide estimates of the net heat flux to the ocean and the significant wave height and period.

The subsurface boom was deployed on the ASIT and instrumented during the second half of the IOP. The sensors included a horizontal array of ADVs paired with thermisters. These measurements were used to compute subsurface stresses and heat fluxes during the IOP (Trowbridge et al., 2004; Gerbi et al., 2006). To obtain these fluxes, a technique that relies on differencing velocities obtained from horizontally separated ADVs is used to remove the irrotational motion of the surface waves. To our knowledge, this is the first comparison of coincident direct covariance Reynolds stresses and heat fluxes measured on both sides of the interface.

The Nobska conducted 4 cruises during the IOP in a wide variety of conditions. The Nobska was outfitted with a direct covariance flux system (DCFS), IR radiometers to measure the SST, and a towed thermistor chain to measure upper ocean temperature structure at very high vertical resolution during transects in the CBLAST region. Some of the towed array results have been processed and combined with the DCFS results that clearly show that the surface fluxes are rapidly responding to the spatial variability in the SST field (Edson et al., 2007).

Basic processing and application of post-deployment calibrations to our data from the 2003 IOP is complete and further processing and quality control is ongoing. Relevant portions of the data have been transferred to John Wilkin (Rutgers) for initialization and testing of the high resolution Regional Ocean Modeling System (ROMS), to Shouping Wang (NRL) for comparison with COAMPS (Coupled Ocean/Atmosphere Mesoscale Predictions Systems), to Larry Mahrt (OSU) for comparison with aircraft measurements, and to Peter Sullivan (NCAR) for comparison with Large Eddy Simulations of wind-swell interactions.

Results based on analyses of our data have been presented at the 2004 AGU Ocean Sciences Meeting (Farrar *et al.*, 2004; Crofoot et al., 2004; Edson et al., 2004b; Hristov et al., 2004b; Mahrt et al., 2004), the 2004 AMS 16th Symposium on Boundary Layers and Turbulence (Edson et al., 2004a; Hristov et al., 2004a; Sullivan et al., 2004; Trowbridge et al., 2004; Wang *et al.*, 2004a, 2004b), the 2005 Gordon Research Conference on Coastal Ocean Circulation (Edson, 2005), 2006 AGU Ocean Sciences

Meeting (Gerbi *et al.*, 2006), and 2006 AMS 27th Conference on Hurricanes and Tropical Meteorology (Edson et al., 2006; Sullivan et al., 2006; Sun *et al.*, 2006).

RECENT RESULTS

An overview of the CBLAST-LOW program was published in the Bulletin of the American Meteorological Society (Edson *et al*, 2007). A number of the preliminary investigation described in the overview where completed and published during the year. This grant supported the PIs efforts in two of these investigations. The first involved the investigation reported by Gerbi *et al*. (2007) entitled "Direct Covariance Measurements of Near Surface Turbulent Momentum Flux in the Coastal Ocean." This paper combined the atmospheric flux measurements with direct measurements of the momentum and heat fluxes computed in the oceanic mixed layer. To our knowledge, this represents the first successful attempt to measure directly and simultaneously the heat and momentum exchange on both sides of the air-sea interface. The second involved the investigation report by Sullivan *et al*. (2007) entitled "Large Eddy Simulations and Observations of Atmospheric Marine Boundary Layers above Non-equilibrium Surface Waves." This paper combined measurements with LES to investigate the exchange of momentum during low wind conditions over swell. The LES results indicate that the dominant forces above the waves in this region are a wave-induced momentum flux divergence that accelerates the flow and a retarding pressure gradient, i.e., opposite to the momentum balance in classical boundary layers. Under these conditions, the wave driven winds produce a low-level jet and a rapid decay of the momentum flux with height. In principle, this upward exchange of momentum is expected to reduce the total momentum flux, and we hypothesize that this will lead to a reduction in the drag at low wind speeds under these conditions. Evidence for this is seen in Figure 2, where measured drag coefficients from ASIT fall below the commonly used COARE 3.0 algorithm. If the COARE parameterization is correct for mature seas at all wind speeds, then the bin-averaged results indicate that the drag coefficients of the older seas are suppressed. The figure also shows, however, that the difference between the drag coefficients for wind speed bins that have more than one wave-age category is not significant. As such, these results, by themselves, are not sufficient to conclude that wave-age is the cause for the discrepancy (i.e., COARE may simply overestimate the drag at low wind speeds for all wave-ages). Therefore, we are currently combining these results with measurements made during the ONR sponsored MBL, RASEX and OHATS programs.

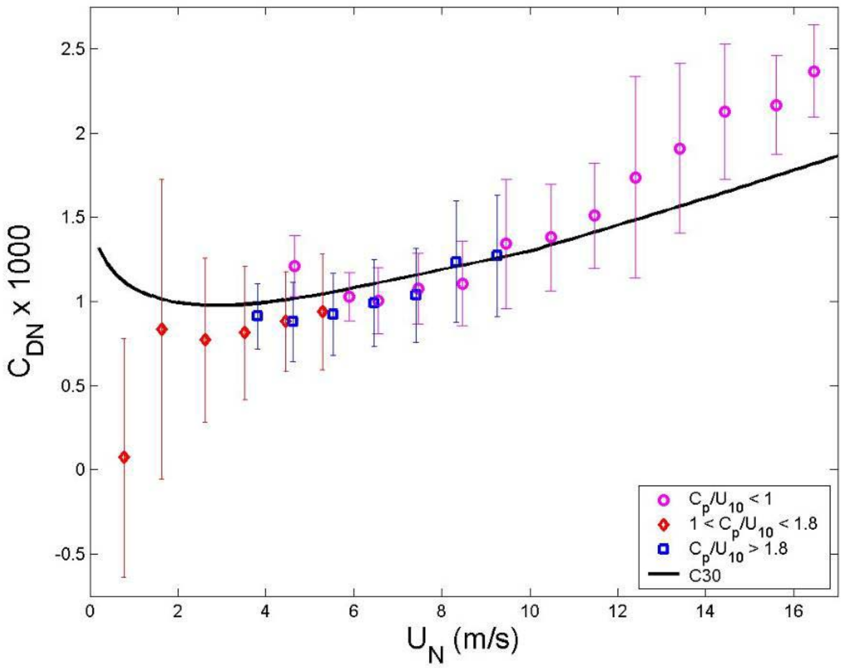

Figure 2. Bin-averaged estimates of the neutral drag coefficients using three subsets of data representing young, mature and old seas.

IMPACT/APPLICATIONS

The 2003 IOP component of the CBLAST field program was successfully completed in October, 2003. Data quality and return have been excellent, and a wide variety of conditions were sampled, including low-to-moderate wind conditions and the passage of strong atmospheric and oceanic fronts through the study region. The ASIT and the fifteen moorings that were deployed provide a complete time series of the passage of oceanic fronts and other processes with a spatial resolution on the order of 4 km, and the ship based measurements complement this data by providing a spatial resolution of about 8 m. In conjunction with aircraft-based measurements and satellite data, the *in situ* measurements collected during the 2003 IOP constitute an unprecedented record of the evolution of the coupled air-sea boundary layers. These measurements will facilitate a more complete understanding of the relative roles of local air-sea interaction and other processes (e.g. ocean fronts and advection) in influencing the evolution of the coupled air-sea boundary layer in low-to-moderate winds. Through ongoing collaboration with numerical modeling groups, we anticipate that this data and improved understanding of air-sea interaction will contribute directly to improving the skill of marine forecasts.

TRANSITIONS

In addition to several ongoing ONR projects, the ASIT is being used by investigators funded by the NSF and NASA to conduct their research. The ASIT has become a component of the MVCO.

RELATED PROJECTS

James Edson, in collaboration with Peter Sullivan (NCAR) and John Wyngaard (PSU), has used the ASIT in an NSF and ONR jointly sponsored program entitled *Ocean Horizontal Array Turbulence Study (OHATS): An Investigation of Subfilter-Scale Fluxes in the Marine Surface Layer*. Detailed information about this project is provided in the ONR annual report submitted by Sullivan.

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